Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Erosion During Hurricane Isabel**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval Research Laboratory,4555 Overlook Avenue SW,Washington,DC,20375**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR’S ACRONYM(S) 11. SPONSOR/MONITOR’S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**3**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

Erosion During Hurricane Isabel

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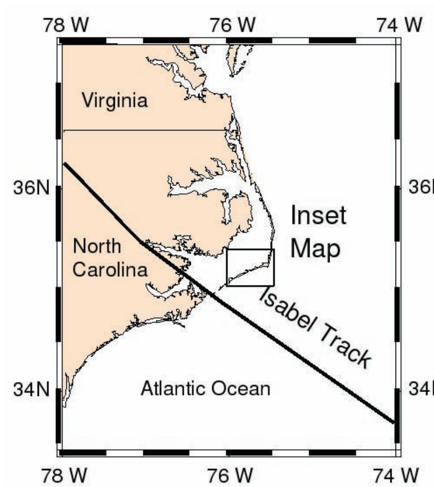
Introduction: A better understanding of the complex interplay between ocean waves, water levels, and currents, and the movement of sediment in the dune-beach system will improve predictions of coastal environmental hazards, water-column optics, bar movement, and mine burial—all of which have tactical implications. Historically, this interaction of different processes has been modeled by using simple parameterizations. In this study, we explicitly simulate the above processes through a suite of numerical models. We use a depiction of the landfall of Hurricane Isabel (2003) on the barrier islands of Cape Hatteras, North Carolina, to examine potential erosion that contributes to barrier island breaching and washover. This prototype for a rapidly relocatable nearshore sediment transport modeling system will take advantage of recent advances in Navy technology for global deep-ocean and coastal environmental modeling.

Modeling Coastal Erosion: We coupled a suite of individual models representing different physical ocean processes. The ocean environment is simulated using a parametric model of tropical cyclone winds; a numerical model for the surface gravity wave field in coastal areas (Simulating WAves Nearshore[1]); and the Navy Coastal Ocean Model[2] for the coastal ocean tides and currents. Sedimentation and erosion processes are simulated using the Littoral Sedimentation and Optics Model,[3] which couples a bottom boundary layer model representing the interaction of the waves and currents near the seabed with a sedimentation model. The sedimentation model calculates potential erosion, which is the volume of sediment per unit coastline length removed from the adjacent land point.

We show that when the modeled potential erosion exceeds the material available for erosion in the dune-beach system, dune removal and washover may occur. If there is a substantial difference in water levels on the offshore and onshore sides of the barrier island, a pressure gradient can drive a cross-island flow, and a breach channel may develop. Using simple geometric arguments based on the average height of the dune-beach system before the storm, the tide and storm surge water levels depicted by the circulation model, and the conservation of the volume of sediment eroded from the dune-beach system, we derive a critical dune system mean height, $H_c = E/L + n$, where E is the model potential erosion due to the storm, L is the width of the dune-beach system, and n is the model offshore water level due to storm surge and tides. When H_c exceeds the actual mean height of the dune-beach system, there is the potential for washover, and if the difference of water levels across the island is significant, for breaching.

Hurricane Isabel at Ocracoke and Hatteras Islands: The modeled oceanographic factors all reach their maximum intensities along Hatteras Island during the 12-h period around Isabel's landfall at 1100 UTC on 18 September 2003 (Fig. 10). Modeled waves near Hatteras Island exceed 7 m. Modeled currents



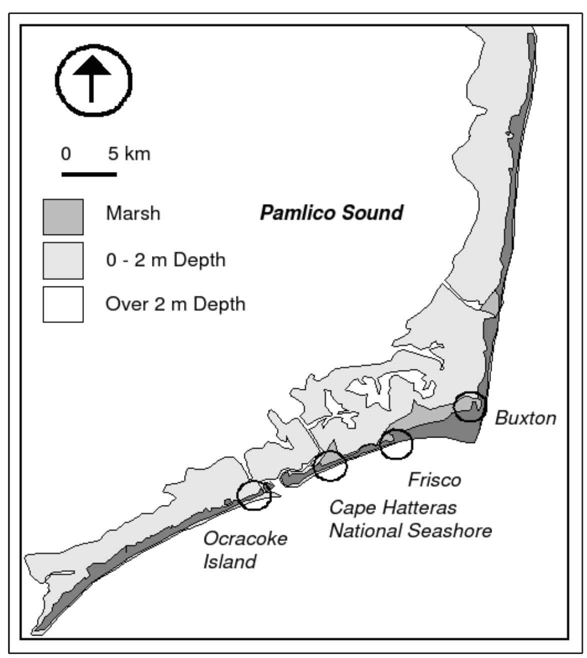


FIGURE 10
Map of the Outer Banks area showing the path of Hurricane Isabel on 18 September 2003. The inset map shows the Cape Hatteras locations (circled) discussed in the text.

along south Hatteras Island are westward during the storm build-up and peak at more than 1 ms^{-1} prior to landfall, then reverse direction with the shift in the wind direction as the eye moves inland. The tidal signal dominates the regional pattern of predicted water level, and adds to the storm surge setup that extends from Ocracoke Island eastward and northward along Hatteras Island (Fig. 11). Substantial set-down on the inshore side of the barrier islands establishes a large (0.5 to 1 m) cross-island water level difference.

The National Oceanic and Atmospheric Administration (NOAA) flew several reconnaissance flights over the Outer Banks after Hurricane Isabel to assess the damage. The erosion observed in the aerial photography is consistent with the alongshore variation in the model potential erosion (Table 2). For example, at the eastern end of Ocracoke Island (50 km from landfall), washover terraces and perched fans were deposited 650 m inland (Fig. 12(a)). In contrast, in the Cape Hatteras National Seashore along the western end of Hatteras Island (60 km east of the storm track), newly incised channels in addition to dune erosion and washover deposition are evident (Fig. 12(b)). The lower dunes and smaller volume of sand there imply a smaller mean height and a greater vulnerability to the higher critical height value. The observed damage to the barrier island suggests that indeed the critical height exceeded the actual dune-beach system mean height. Overall, the comparison between the model results and the observed erosion indicates that where the reservoir of sand in the dune-beach system was insufficient, the dunes were removed and breaching occurred.

Future Developments: The coupled modeling approach depicts the complexity of interacting ocean and sedimentation processes, and shows promise for further study of beach erosion and breaching during such notable storms as Hurricanes Ivan and Katrina. Ongoing development at NRL of accurate, relocatable, coastal models for the littoral environment and sedimentation processes to include additional processes such as wave-driven flow and inundation will better support a wide range of Navy applications.

Acknowledgments: Aerial photographs of the Outer Banks were acquired from the North Carolina Geodetic Survey.

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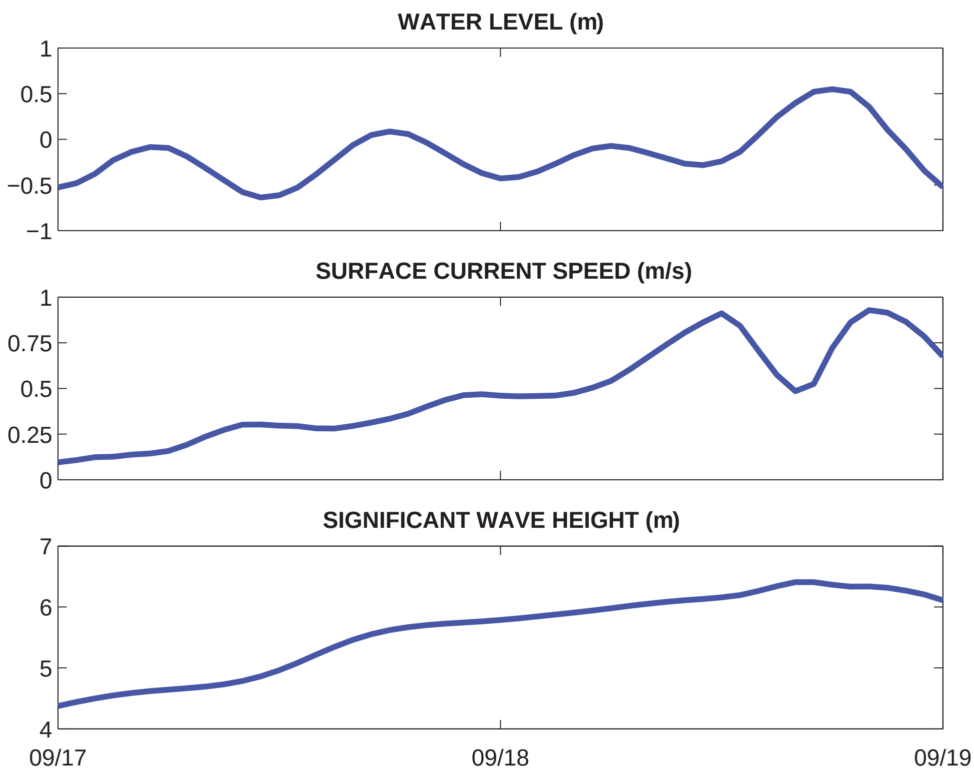
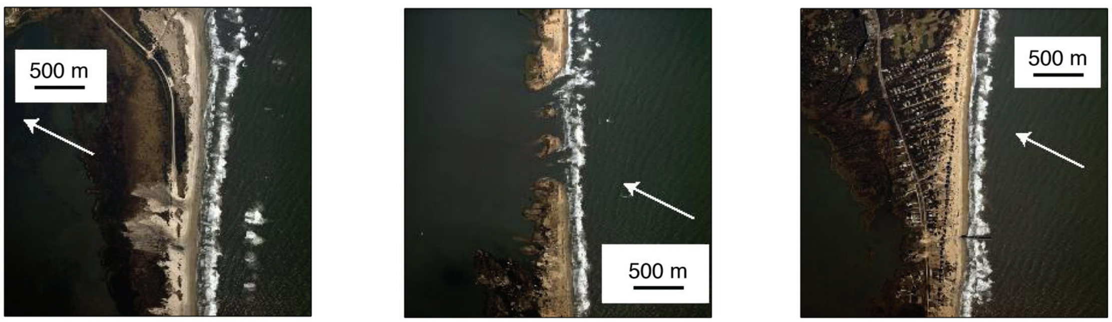


FIGURE 11
Oceanographic conditions at Ocracoke Island before and during landfall of Hurricane Isabel: the offshore water level showing the combined effect of tides and storm surge (top), the surface current speed (middle), and the significant wave height (bottom). The bottom axis shows the 0000 UTC times for 17-19 September 2003. The storm made landfall approximately 50 km west of this location at 1100 UTC 18 September.

Table 2 — Estimates from the aerial photography of the dune-beach width L, predicted values of the erosion potential E, the water level n, and the critical height H_c, at three locations along the North Carolina Outer Banks during the landfall of Hurricane Isabel in September 2003.

Location	L	E	n	H_c
Ocracoke Island	250	38	0.55	0.70
Cape Hatteras National Seashore	100	65	0.58	1.20
Frisco	200	7	0.54	0.58



(a) Ocracoke Island (b) Cape Hatteras National Seashore (c) Frisco

FIGURE 12
Aerial photographs taken after Hurricane Isabel on the Outer Banks. The photographs are oriented with Pamlico Sound to the left.

References

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[3] T.R. Keen and S.M. Glenn, "A Coupled Hydrodynamic-Bottom Boundary Layer Model of Ekman Flow on Stratified Continental Shelves," *J. Phys. Oceanogr.* **24**, 1732-1749 (1994). ★